Reference Data Generation of Spray Characteristics in Relation to Large 2-Stroke Marine Diesel Engines Using a Novel Spray Combustion Chamber Concept

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Abstract

The availability of appropriate reference data for combustion in large 2-stroke marine diesel engines is a prerequisite for the further development of Computation Fluid Dynamics tools. In order to enable the acquisition of such data at relevant physical dimensions (bore) and operational parameters (pressure, temperature), including flow characteristics (swirl) and the low fuel qualities involved, a novel experimental test facility has been realized. The core element is a disk-shaped constant volume spray combustion chamber of diameter 500 mm with peripheral injection into a swirl flow. Thermo- and fluid dynamic conditions at start of injection similar to those in real engines are achieved by feeding the chamber via inclined intake channels with pressurized and heated process gas provided by a pressure vessel/heat regenerating system. The chamber design includes comprehensive possibilities for optical access as well as various injector arrangement options and the injection system is prepared for running on typical marine fuels. Reference data for the fuel spray propagation has been acquired by means of shadow-imaging measurements: This involved the variation of key parameters such as gas pressure and temperature (up to 9 MPa, 930 K), number of injector orifices (1/2/5) and the spray orientation (10 deg counter- to 40 deg co-swirl) relative to the gas flow. The spray propagation data collected at conditions representative of the operation of large 2-stroke marine diesel engines contributes to a better understanding of the underlying phenomena and enable the validation of simulation tools at such conditions. The new spray combustion chamber thus fills a clear gap and must be considered a reference setup for those applications.

Introduction

Limitations continue to apply for the utilization of currently available Computational Fluid Dynamics (CFD) tools for the combustion system development and optimization of large 2-stroke marine diesel engines. The mere dimensions (bore/stroke up to 960/3150 mm), time scales (down to 61 rpm) and specifics (e.g. injector/nozzle size) already constitute a major challenge and particularly the spray models could only be validated against data from small combustion chambers [1]. Various investigations using optically accessible constant volume vessels have been reported (e.g. [2], [3]) but to study combustion processes at conditions typical of large 2-stroke marine diesel engines, a novel test facility [4] involving the following features has been realized:

- Combustion chamber of sufficiently large dimensions, pronounced swirl pattern of the gas phase.
- Peripheral injection, equipped with multiple orifices of different orientation, varying size of the individual orifices being in the one millimeter range, to be able to simulate a two- or three-injector configuration.
- Pressure and temperature levels at start of injection (SOI) exceeding 12 MPa and 900 K.
- Fuel system able to cope with a wide range of (low) fuel qualities.

Test Facility Setup and Measurement Methods

The spray combustion chamber (Ø500x150 mm) allows the investigation of in-cylinder processes (up to 20 MPa peak firing pressure) such as fuel injection and evaporation, ignition, combustion and emission formation. In order to achieve realistic conditions at the start of injection, a heated and pressurized air (or N_2) flow through inclined inlet ports is provided by a pressure vessel/heat regenerating system (see Figure 1). Optical access (Ø100 mm) is granted by sapphire windows located at different radial positions in the revolvable covers. Fuel admission is realized through (one or two interacting) injectors located at mid-height of the chamber on its circumference, which are fed by an injection system (common rail, pressure up to 100 MPa) similar to those installed on the most recent production engines. The requirement specifications have been validated thoroughly – pressure and temperature levels of up to 13 MPa and more than 930 K (before injection/combustion) as well as the swirl level target velocity range (15-25 m/s) can be achieved at the same time. Thus, its applicability for the intended purpose has been demonstrated [5].

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The spray propagation inside the chamber has been visualized by means of an improved "Shadow-imaging" method using a pulsed diode laser light source. Due to a very short 50 ns laser pulse within a 1 μs exposure time of a high-speed CMOS-camera (20 kHz, 512x512 pixel) in combination with an appropriate narrow band pass filter, an increase of the recordings signal-to-noise ratio is achieved. In addition, also the flame light is suppressed and spray visualization becomes feasible under reactive conditions.

Results and Discussion

An extensive number of systematic measurements for determining the spray evolution at different chamber conditions (3, 6, 9 MPa, 930 K) and injection parameters has been performed. Figure 2 shows a selection of single-hole nozzle cases with spray orientation varying from 10 deg counter-swirl (a), perpendicular to the swirl (b), 15 deg co-swirl (c), and a 40 deg co-swirl (injector-co-axial) orientation (d). The effect of spray orientation is materializing in a reduced penetration in the counter-swirl orientation case which is even more pronounced at multi-hole nozzle configurations. At the two spray configurations case shown in Figure 3, the well-known dependence of spray behaviour on the gas density is observed: With increasing chamber pressure, the penetration is reduced and the spray plumes are becoming wider, especially near the spray tips. Furthermore, there seems to be a shielding effect exerted by the more counter-swirl oriented spray which reduces the interaction of the second spray with the gas flow in the combustion chamber, resulting in a longer conservation of the initial momentum of this spray. Figure 4 shows the behaviour of the two (lower/upper) cone angles with respect of the symmetrical nozzle orifice axis according the variation in pressure. The upper cone angle is very much affected due to the swirl flow, whereas the lower cone angle remains constant. The analysis of more complex configurations (spray interaction) can be expected to provide substantial additional insight regarding the validation of CFD models.

Acknowledgement

The present work has been conducted as part of the HERCULES-β project within EC's 7th Framework Program, Contract SCP7-GA-2008-217878. Financial support by the Swiss Federal Government (SER & SFOE Contract 154269, Project 103241) is gratefully acknowledged.

References

[1] Schneider B., *PhD thesis*, No. 15004, ETH Zurich, 2003.
[2] Pickett L.M., Siebers D.L., *Combustion and Flame* 138:114-135 (2004).
[3] Bruneaux G., *Atomization and Sprays* 11:533-556 (2001).
[4] Herrmann K., Schulz R., and Weisser G., *CIMAC Congress*, Paper No. 98, Vienna, Austria, May 2007.
[5] Herrmann K., et al., *ICLASS 2009,* Vail, Colorado USA, July 2009.

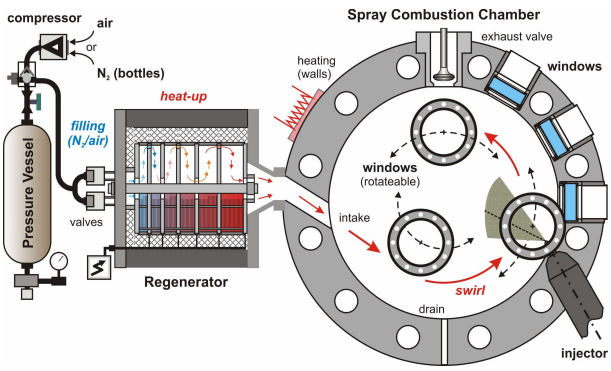

Figure 1. Principle spray combustion chamber facility

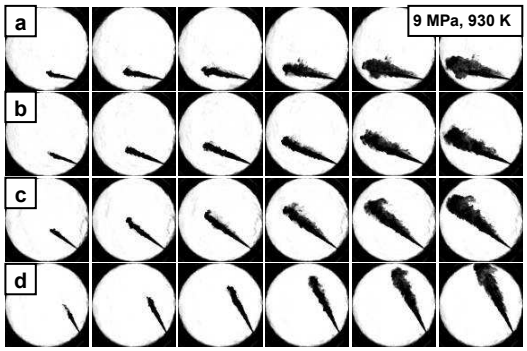

Figure 2. Single-hole nozzle spray evolution

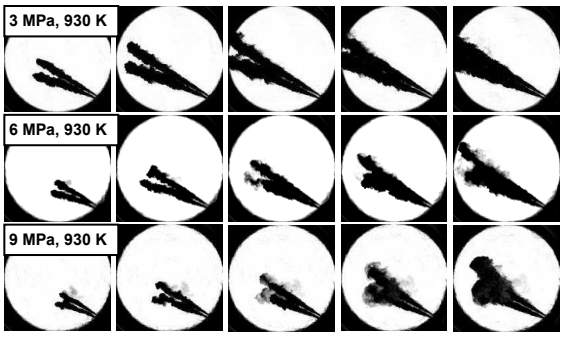

Figure 3. Two-hole nozzle spray evolution

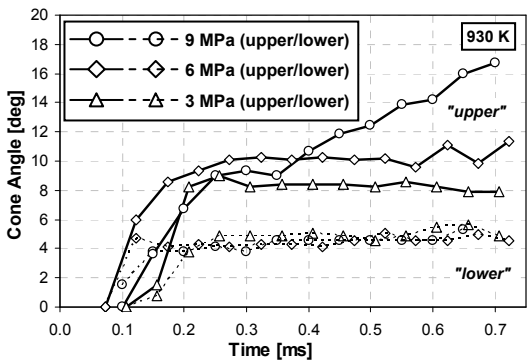

Figure 4. Upper and lower spray cone angle